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ABSTRACT

Reviewed are technological problems faced in energy production including locating, recovering, developing, storing, and distributing energy in clean, convenient, economical, and environmentally satisfactory manners. The energy resources of coal, oil, natural gas, hydroelectric power, nuclear energy, solar energy, geothermal energy, winds, tides, fuel cells, magnetohydrodynamics, hydrogen, and various storage devices are discussed. Energy transmission and diagrams illustrating energy demands, electrical generation capacity, and energy converter efficiencies are included. (SL)

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ENERGY TECHNOLOGY

by William W. Eaton



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For 3 years he served as Deputy Assistant Secretary for Science and Technology in the U. S. Department of Commerce. He has also been prominent in science affairs in Maryland. He headed formal studies on the environmental effects of nuclear power plants, both for the Governor of Maryland and for the Southern Governors' Conference.

Dr. Eaton has written articles in a number of technical fields, including several related to various aspects of energy. For ERDA, in addition to this booklet, he has written "Geothermal Energy" and "Solar Energy".

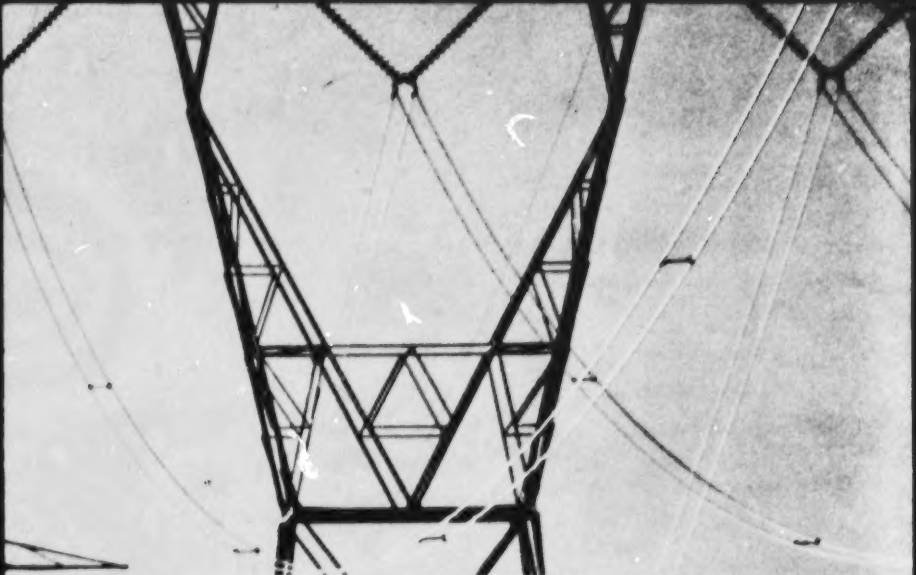
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Introduction

The availability to the public of adequate quantities of energy—to do mechanical work, provide heat, supply transportation, and generate electricity—is one of the most important characteristics of a civilized society.

In the United States, we are fortunate in having tremendous energy resources that have been used in hundreds of applications which affect our daily lives. This country, with only 6% of the world's population, now uses about $\frac{1}{3}$ of the total energy expended throughout the world. Despite large domestic resources, the U. S. imports about 18% of the total energy it consumes.

The term "energy technology" covers the application of all scientific and engineering knowledge to the complex problems of locating, recovering, developing, storing, and distributing various forms of energy in a clean, convenient, and economical manner.

In our rapidly changing society, which continues to demand ever-increasing amounts of energy, it is essential that we constantly explore new methods of improving energy technology, so that we can meet our future energy requirements at a reasonable cost and without damaging the

environment or seriously depleting precious natural resources.

Many organizations—governmental, university, and industrial—are now devoting increased efforts to various aspects of energy technology. Some of these efforts are concerned with the important problems of energy storage, conservation, and transmission. Others include solar energy, geothermal energy, and coal gasification and liquefaction.

The purpose of this booklet is to provide some general information on the subject of energy technology, such as: what our energy resources are, how we use them, what we are doing to improve methods of storing and transmitting energy, and what can be done to plan for intelligent utilization of energy in the future.

In addition to this broad picture, specific information on new types of energy resources is included, as well as a discussion of the relationship between energy utilization and the environment.

Many important subjects, such as energy conservation (especially end use), development of alternative technologies for automobile engines (more efficient ones and those using alternative fuels), energy recovery from municipal and industrial waste, etc., are not covered. For those interested in a more detailed study of energy technology problems, there is a bibliography on pages 59 and 60.

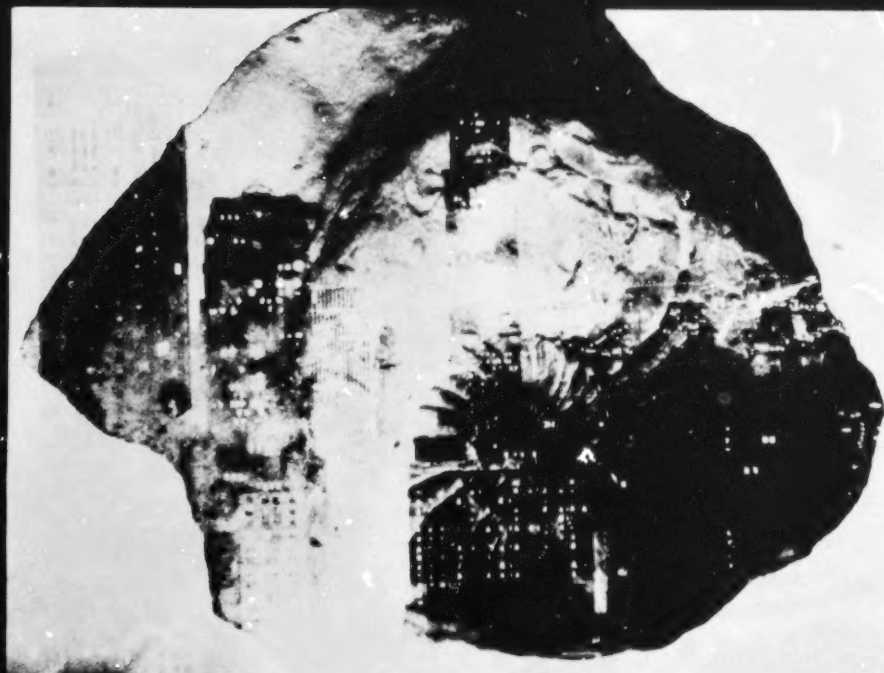


Figure 1 Most electricity is produced through the burning of fossil fuels — coal, gas, and oil.

The Nature of Energy

Energy is the capacity for doing mechanical work, creating heat, or generating electricity.

Energy exists in many different forms, the most important of which are described briefly below. The efficient conversion from one form to another for various specific applications is one of the basic objectives of energy technology, and is discussed in the chapter on energy conversion on page 39. Another goal is to find convenient methods of storing and transmitting energy so it can be used where and when it is needed. These subjects are covered in the chapters on energy storage on page 46 and energy transmission on page 53.

KINETIC ENERGY

Kinetic, or mechanical, energy—the energy of motion—is one of the commonest forms. Automobiles, trains, planes, and other vehicles provide transportation through their kinetic energy.

For many centuries, the kinetic energy of wind provided the power source for sailing ships and windmills, but these applications have steadily diminished during the last hundred years because of the increased availability of other more reliable energy sources.

The kinetic energy of moving water was also historically significant because it supplied, through the water wheel, the principal means to operate mills and factories in the early days of industry. This method is still used in some developing countries throughout the world.

Electric power is derived from hydroelectric plants that use the kinetic energy of water flowing from a reservoir to operate turbines which in turn run electrical generators. (See also the chapter on energy resources on page 14.)

Other familiar examples of kinetic energy are the explosive forces produced by dynamite, flying bullets and other projectiles, air hammers and earth-moving equipment used in construction work, and electric motors, which produce rotating kinetic energy for a multitude of applications.

HEAT ENERGY

Heat energy produced by burning fossil fuels was used until modern times mainly for heating and cooking purposes. During the last two centuries, it has been increasingly used in industry and transportation to operate turbines or engines powered by heat-generated steam.

Since the beginning of this century, a steadily increasing fraction of the total heat energy used has been applied to generate electricity.

ELECTRICAL ENERGY

Electricity is a special kind of intermediate form of energy used by civilized man mainly in the 20th century. It can be conveniently converted to kinetic energy in a clean and economical fashion, or converted directly into heat or light, or used for many different communications applications and other special purposes.

Because of this versatility, convenience, and relatively low cost, the U. S. demand for electricity has been doubling roughly every 10 years in recent times, and we now generate and use about one-third of all the electricity produced in the world. Electricity has been used to reduce the drudgery and enhance the quality of life, and the widespread availability of electrical energy has become a hallmark of civilization.

RADIATION ENERGY

Radiation is another kind of energy existing in the form of electromagnetic waves that travel through space at a very high speed. Examples are sunlight, which consists primarily of heat and light; radio waves, which are used for communications purposes, and X rays, which are used for medical diagnosis.

Radiation from the sun, or solar energy, is the source of virtually all the energy used in the world. For example, all fossil fuels are indirectly the result of the sun's radiation, which helped to create the vegetation that over millions of years has been transformed into coal, oil, and gas.

The heat in sunlight causes the evaporation of a fraction of the earth's water into clouds that produce rain, some of which goes into rivers and in turn provides the water power

mentioned above. Similarly, the heat of the sun's radiation indirectly produces kinetic energy in the earth's winds. Further use of solar energy is discussed in the chapter on energy resources on page 14.

POTENTIAL ENERGY

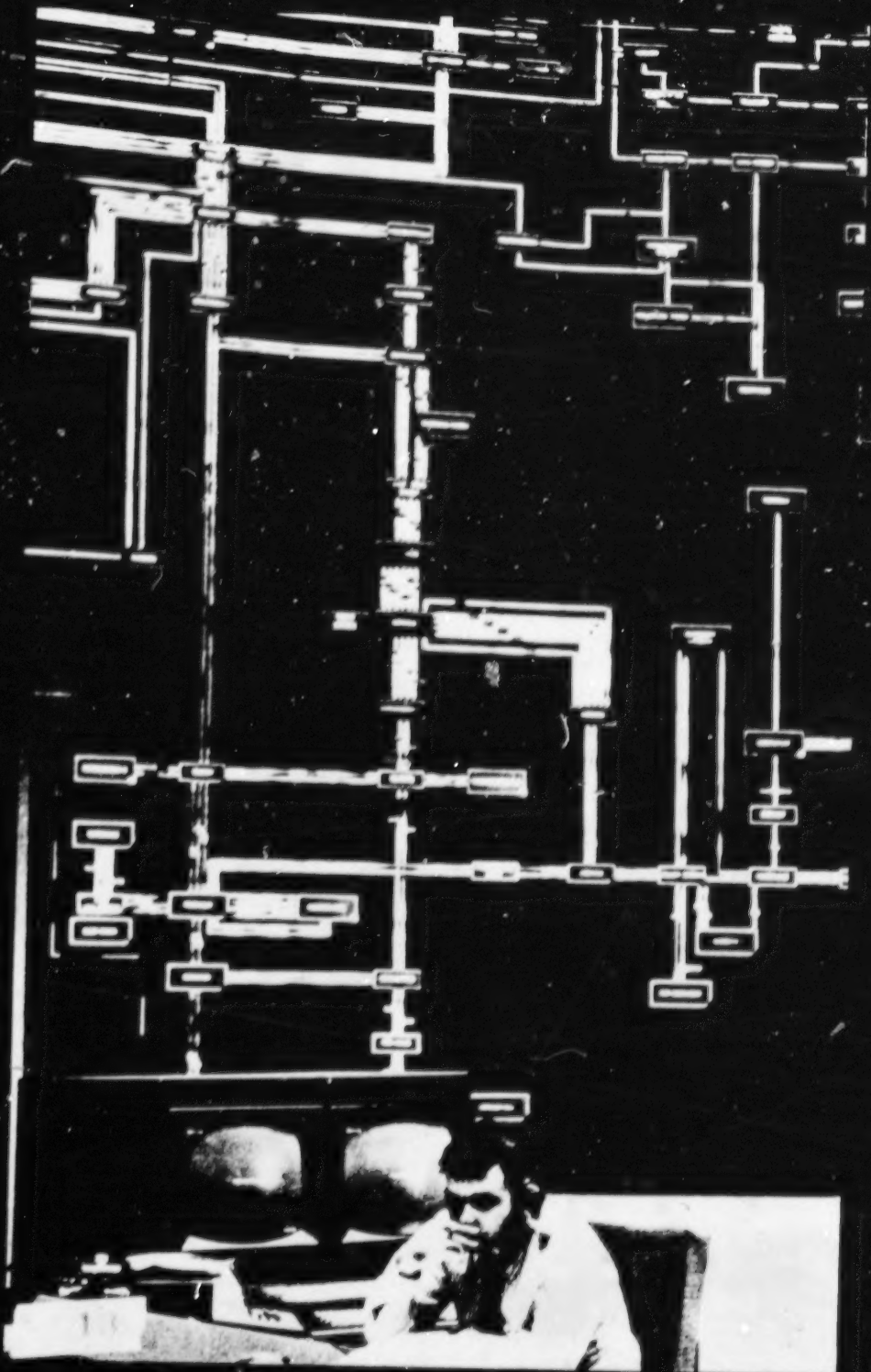
Potential energy exists in an inactive form but has the potential to produce usable energy when properly activated.

For example, water in a reservoir, as mentioned above, has potential energy because kinetic energy is produced when the water flows to a lower level.

Fossil fuels—such as coal, oil, and gas—all possess potential energy in a chemical form since heat or kinetic



Figure 2 The United States uses one-third of all the energy in the world, but has only 6% of the world's population.



energy is produced if these substances are burned or exploded as a result of chemical reactions.

Nuclear fuels also contain large amounts of potential energy that can be converted to heat or kinetic energy.

Energy can be stored mechanically in compressed metal springs, as in watches, automobiles, and toys, that will produce kinetic energy. Compressed air is another illustration of mechanically stored potential energy.

Finally, an electric battery is an important example of potential energy, because it contains chemically stored electricity that can be conveniently used upon demand.

ENERGY AND POWER

In working with energy problems, it is essential to differentiate clearly between *energy*, which represents the *total amount* of work or heat or electricity involved, and *power*, which measures the *speed* with which the energy is expended.

There is often confusion between these two terms, which are sometimes used loosely. In simple terms, energy is more like what we think of as "work", while power resembles our concept of "effort".

For example, an elevator of low power capacity expends the same total amount of energy in lifting a load slowly between two floors as a higher power elevator that travels the same distance faster.



Figure 3 The control center of the New York Power Pool. Whenever a plant or line falters, lights flash on the wall. The dispatcher immediately selects substitute lines and power sources to keep the electricity flowing. The pool was created after the blackout of the northeastern United States and part of Canada in 1965.

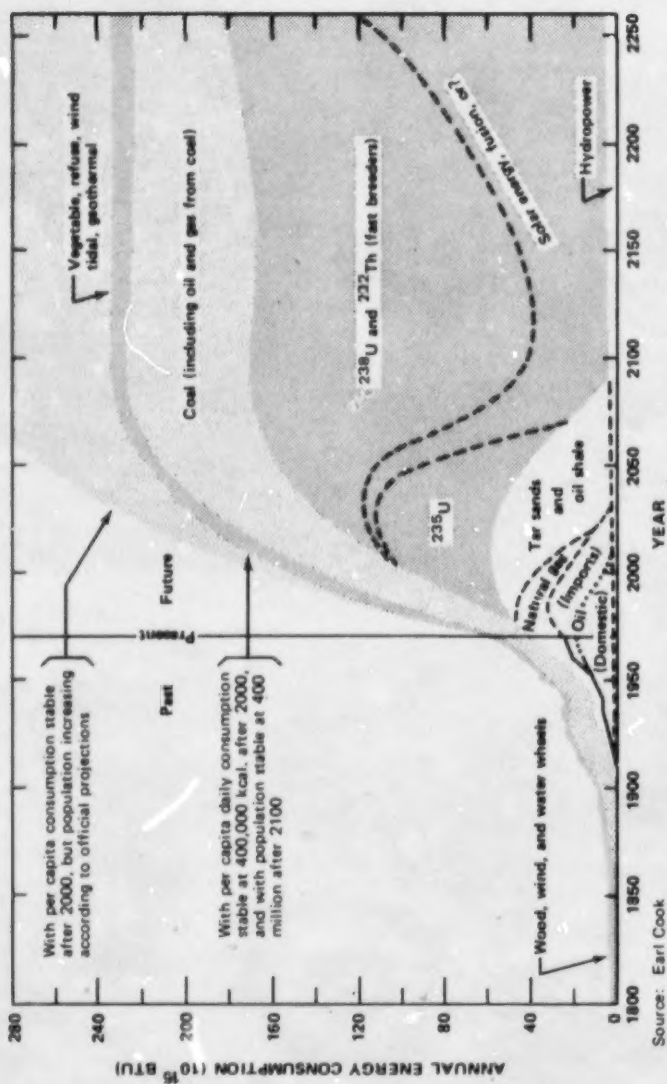


Figure 4 Past, present, and future energy resources.

Similarly, the total amount of potential energy stored in a gallon of gasoline may be expended rapidly in a high-powered automobile or slowly in a low-powered lawn mower.

Power is often measured in *horsepower*, which is a somewhat arbitrary unit related only roughly to the capabilities of the average work-horse. One horsepower represents the effort required to lift a 550-pound weight 1 foot in 1 second.

ELECTRICAL TERMS

Since electricity is one of the most convenient and common forms of energy we have, it is helpful to know something about a few of the basic electrical terms. Electrical voltage—measured in number of volts—is something like the pressure in a closed water system, while the current—measured in number of amperes—is comparable to the volume of water flowing in the system. The power used in a circuit in watts is obtained by multiplying the number of volts in an electrical circuit by the number of flowing amperes. One thousand watts, or 1 kilowatt, is equal to $1\frac{1}{3}$ horsepower.

Electrical energy in homes and factories is paid for on the basis of total consumed kilowatt-hours, which are the number of kilowatts used multiplied by the number of hours of use. To put this unit into perspective, a kilowatt-hour can be visualized as the energy represented, for example, by ten 100-watt lamps burning for 1 hour, or five 50-watt lamps burning for 4 hours, or a 1000-watt appliance being used for 1 hour.

Energy Resources

This chapter describes present energy resources and trends in their use and provides information concerning possible new resources that may be important in the future. See Figure 4 for an overview of past, present, and future energy resources.

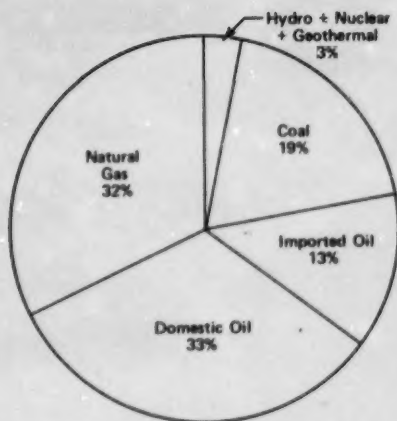
Figure 5, based on data from the U. S. Department of the Interior, shows an estimated breakdown of the major energy resources used in the U. S. in 1973. (The next chapter contains data about the end uses and applications of these resources.)

Rapid and significant changes are currently taking place in the availability and usefulness of many important energy resources and are described in detail below. Indications are clear that the demand for energy consumption will continue to rise steadily. During the last 30 years of this century, the U. S. is expected to use more energy than during its entire previous history!

These changes in energy supply and demand have caused many problems, which are being referred to collectively as the "energy shortage" or the "energy crisis". Outlined in the following paragraphs are summaries of the important facts relating to present and possible future resources to meet expected energy demands in an acceptable manner.

COAL

The U. S. has large deposits of coal, our most plentiful fossil fuel, which theoretically could meet our energy requirements for centuries. However, as Figure 5 shows, coal furnishes only about 19% of our energy needs today. Primarily, this is because there are serious problems in using coal effectively and economically in a manner that will not produce undesirable side effects on the environment.



U. S. ENERGY SOURCES
1973

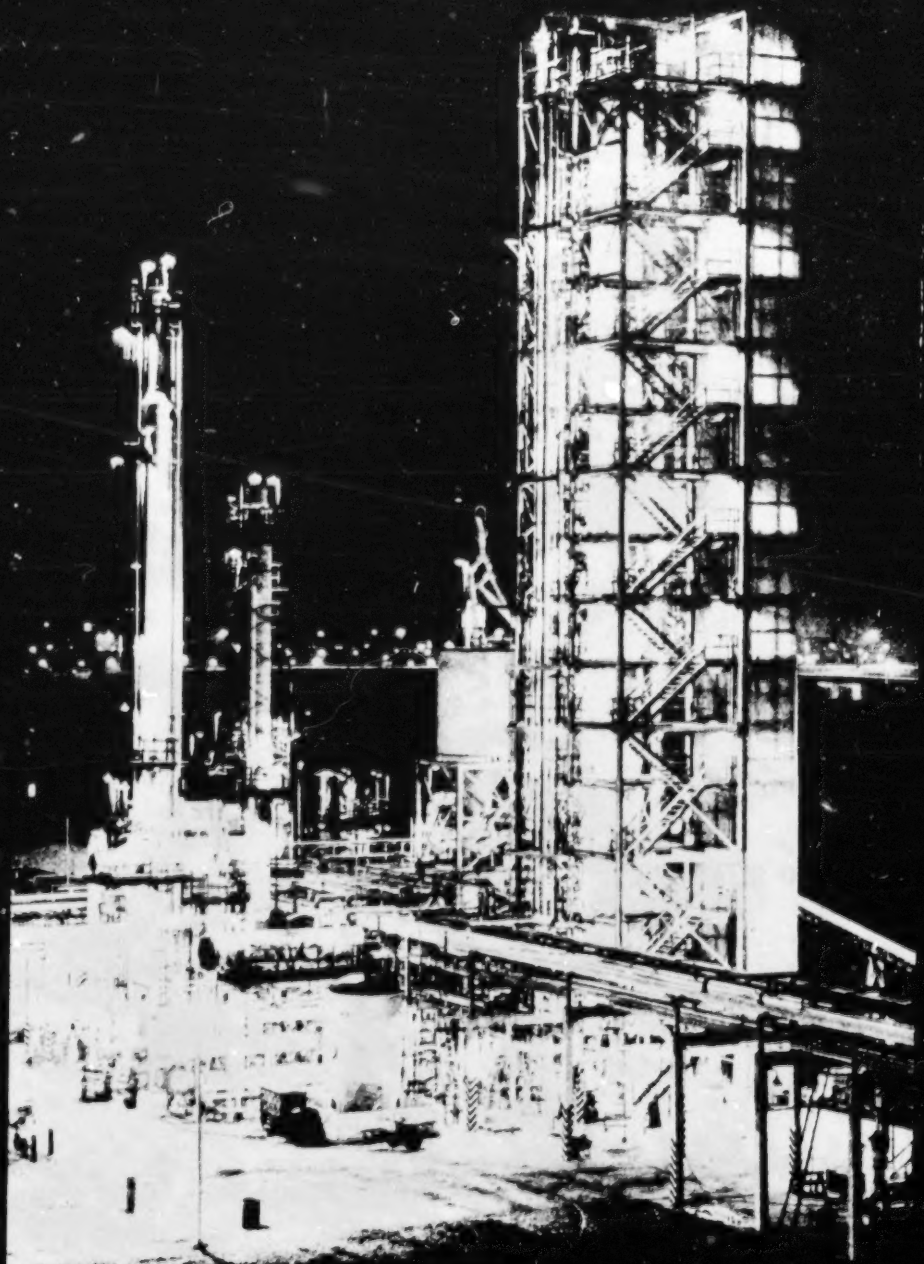
Figure 5

For example, much of the coal located in the eastern U. S. has impurities, such as sulfur, that produce unacceptable air pollution unless expensive pollution control methods are employed.

Conversely, the large deposits of coal located in the western U. S., while relatively low in sulfur content, are of generally poorer quality as a fuel and hence less efficient to burn. Furthermore, these deposits are mostly located at considerable distances from the populated areas where they would be used.

Also, the surface or strip mining necessary to obtain a large portion of this coal causes undesirable environmental effects, which are costly to eliminate and/or repair.

Specific problems requiring careful attention are those related to the methods used to mine underground, strip mine, and restore the land, and the degree of removal of sulfur from high sulfur coal during coal preparation to meet reasonable environmental standards.



In addition to increased use of coal to meet near-term and midterm needs for power generation, coal provides an attractive alternative for midterm to long-term needs for gas and oil and refined products, such as gasoline and certain petrochemicals. Developing this alternative will require an aggressive effort by Government and industry to bring coal liquefaction and gasification to commercial realization. The U. S. Energy Research and Development Administration is currently supporting the development of several such processes, with major emphasis on liquefaction to produce low sulfur boiler fuels and distillate transportation fuels.

OIL

At the present time the biggest problem with oil is that we don't have enough economically recoverable reserves to meet the demand. Therefore, more than a quarter of the petroleum we now use must be imported.

During the first half of this century, extensive and highly sophisticated exploration activities located enough oil to meet the country's needs. Because of low cost foreign oil, however, exploration efforts have slowed down during the last two decades, but demands have continued to increase sharply.

Other ways to increase our supply of domestic oil and/or refined products from a short- through long-term standpoint would be by increased recovery rates from existing wells; offshore drilling; drilling in deeper reservoirs onshore, in onshore stratigraphic traps, and in areas such as Alaska that have not been extensively explored; increased petroleum refinery capacity; advanced processes for upgrading petroleum residues; and the gradual displacement of petroleum-derived boiler fuels, transportation fuels, and certain petro-

 *Figure 6 On the left is ERDA's experimental pilot plant in Chicago that is used to produce a synthetic natural gas from coal.*



Figure 7 The U. S. imports about one-quarter of the petroleum that it now uses.

chemicals, successively, by those derived from coal, lignite, oil shale, and tar sands.

Of 14,000 operating offshore wells there have been a total of 25 blowouts, with 22 of the 25 being of relatively minor importance. About 95% of the spillage of oil by man today results from the overall tanker operations associated with the import of oil. Present indications are that the import of increasing quantities of oil via behemoth 250,000-ton tankers will result in massive coastal pollution. Accordingly, a carefully planned and executed offshore drilling effort, which takes into account environmental concerns and tradeoffs with alternative approaches, could become an acceptable national approach to meeting our Nation's needs for oil.

NATURAL GAS

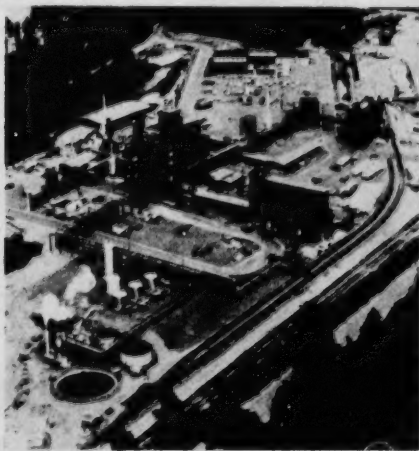
Figure 5 shows clearly the importance of natural gas, which now furnishes nearly one-third of the country's total

energy requirements. As a fuel, gas has many advantages, such as convenience of transport and clean-burning characteristics.

The problem with gas is similar to that of oil, only more serious—there simply isn't enough available to meet demands. The known U. S. gas reserves, even if tapped and used, would be considerably depleted in about 10 years at the current rate of consumption. Even the use of explosives to stimulate gas production, now under careful study, will extend the known supplies only a few years.

To assist in meeting demands, plans are under way to import in the near future large quantities of natural gas in liquid form at very low temperature. However, the same serious long-range economic and national security considerations apply to the importation of natural gas that apply to oil. Our country simply cannot be vulnerable in the long run to foreign energy sources that could be disrupted. Thus, another basic problem of energy technology is how to shift current and projected applications of natural gas to other more abundant domestic fuels.

Figure 8 ERDA's Solvent Refined Coal Pilot Plant in Tacoma, Washington, for the production of a low-sulfur, low-ash coal product.



HYDROELECTRIC POWER

The use of dams and reservoirs for hydroelectric installations has many advantages. The most important of these is that the water is continually replaced by rainfall and so no fuel resource is depleted.

Another plus for hydroelectric power is that the potential energy of the water in the reservoir is converted into kinetic energy and then electricity with a relatively high overall efficiency. Consequently, there is a negligible amount of waste heat dissipated to the environment in contrast with the tremendous quantities of heat thrown off from fossil and nuclear plants operating with efficiencies in the 32 to 40% range.

Thus, while only 5% of the total energy consumed to generate electricity is supplied by water power, the fraction

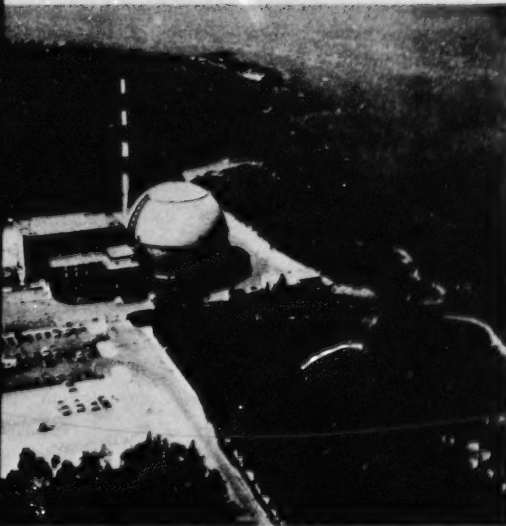


Figure 9 The Big Rock Point Nuclear Power Plant on Lake Michigan began operation in December 1962. It has a 75,000 electrical kilowatt capacity.

of the country's electricity now traceable to hydroelectric plants is about 15%.

Unfortunately, many of the locations in the U. S. that are most suitable for hydroelectric plants are already in use. Hence, there will probably be only a modest increase in the number of such installations during the remainder of this century.

From an environmental standpoint, many hydroelectric plants have turned out to be highly desirable, since valuable recreation and flood control facilities are often created.

NUCLEAR ENERGY

To understand the nature of nuclear energy, it is helpful to know something about the structure of an atom. Although an individual atom is not visible even with the most powerful microscope, there is much experimental evidence to indicate that an atom consists of a relatively small, dense, positively charged nucleus, composed of positively charged protons and uncharged neutrons. The nucleus is surrounded by lighter weight negatively charged electrons. The number of electrons equals the positive charge of the nucleus, and determines the chemical and physical characteristics of the atom's substance.

Chemical reactions between different substances involve interactions between the outer electrons of atoms or molecules (close combinations of two or more atoms). One of the most important of such interactions is burning, or the heat-producing reaction between various fuels and oxygen.

Nuclear energy, on the other hand, is derived from an entirely different process as a result of the interactions between atomic nuclei or their components (such as neutrons) under very special conditions. Such reactions, which take place in a nuclear reactor, include the fission (splitting) of relatively large nuclei, or the combining (fusion) of lightweight nuclei. In either case, the energy available is generally much larger than what results from chemical

reactions. For example, the nuclear energy available from 1 pound of uranium-235 is equivalent to that obtained by burning 3,000,000 pounds of coal.

Light water nuclear power plants do not use pure uranium-235, but a mixture containing about 2 to 5% of this isotope with the remainder being uranium-238. These two kinds of uranium are called isotopes. Isotopes are indistinguishable chemically, but have nuclei of slightly different weights. Uranium found in nature contains less than 1% of the essential uranium-235 isotope; this fraction must be increased by an exceedingly complex and costly procedure called enrichment.

Present-day nuclear power plants are based on uranium fission and depend on the continued availability of this mineral. Although it is reasonably plentiful in the U. S., it is estimated that these supplies would last only a few decades, if current plans to increase nuclear power utilization sharply are carried out. This is why the breeder reactor and the fusion reactor, both of which involve other types of nuclear reactions, are important and will be described later in this chapter.

Sustained nuclear energy reactions, derived from the splitting of atomic nuclei in a controlled chain reaction, have been known only since 1942; their commercial application in electric generating plants dates back only to 1957. It is therefore remarkable that in mid-1975 there were 56 nuclear power plants in operation in the U. S. and 187 more in various stages of planning or construction.

While only 4% of the energy used in 1973 to generate electricity was nuclear in origin, it is estimated that this will rise to 12% in 1975, over 21% in 1980, and more than 33% in 1985.

The increase in the use of nuclear power facilities has been accomplished in spite of certain problems related to the safety of the plants, their potential impact on the environ-

ment, and the ultimate disposal of the small quantities of dangerous radioactive waste produced.

However, by the application of very strict regulations and licensing procedures, the nuclear power industry has achieved an excellent safety record, and the plants have so far had a negligible adverse effect on the environment.

The disposal of the radioactive waste, which is inevitable in the operation of nuclear power plants, is not yet a serious problem since the total quantities are small. A comprehensive technology is being developed to handle such waste by the end of the century.

In summary, the characteristics of the nuclear power plants now operating and planned for the next 20 years are that: (1) they have the important advantage of supplying large amounts of electrical energy from domestically available fuel to meet rapidly rising demands at a time when the U. S. is running short of easily usable fossil fuels, and (2) their principal disadvantages are that the supplies of uranium fuel are not inexhaustible, and strict regulations and elaborate precautions are required to maintain high levels of safety in operation and waste disposal.

Breeder Reactors

Nuclear reactions of the breeder type create, or "breed", more usable fuel than they consume in the process of producing heat within the nuclear reactor.

The breeder reactor (like present-day nuclear reactors) will use uranium-238, which has been enriched with either uranium-235, or plutonium, another nuclear fuel created as a by-product from nuclear power plants. It is called the fast breeder reactor because it uses the fast neutrons generated in fission to sustain the chain reaction in contrast to the currently used light-water reactor, which slows down the neutrons to lower energies in order to keep the reactions going.

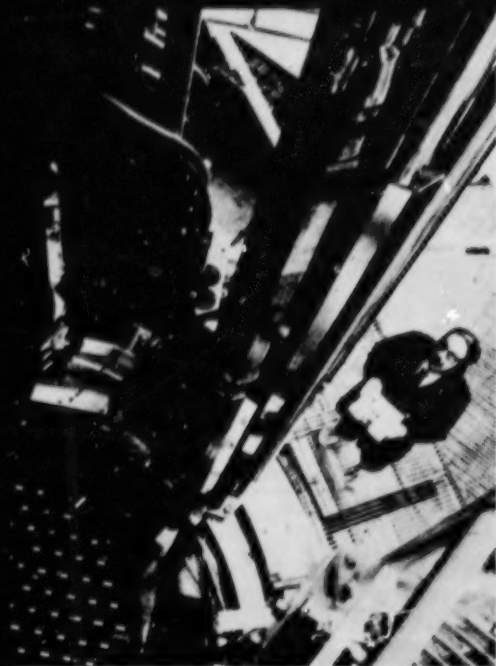


Figure 10 This instrument array, which will be used to monitor the behavior of nuclear fuel during reactor operations, is one component of the Fast Flux Test Facility for developing the liquid metal fast breeder reactor. This facility, now under construction at Hanford, Washington, will provide the necessary experience in designing, fabricating, and operating sodium-cooled nuclear reactors.

The large-scale commercial application of the breeder reactor involves a very complex and sophisticated technology, which is not yet fully developed. Based on all evidence to date, it will play an important role in conserving the world's energy resources. It is estimated that the breeder will help stretch available uranium reserves from decades to hundreds of years.

Another of the breeder's advantages will be its improved overall efficiency, which will mean a reduction in waste heat released to the environment. It is expected that the breeder will be able to operate at a thermal efficiency of about 40% as compared with about 32% for current nuclear plants, an average of 33% for current fossil plants, and up to 40% for all the newer fossil plants.

The advantages of the breeder reactor have stimulated a cooperative development program on the part of all segments

of the utility industry in conjunction with the Energy Research and Development Administration (ERDA). It is estimated that the full cost of the program will be \$2,000,000,000, of which the government has to date spent about \$700,000,000 and industry \$300,000,000.

It is important to realize that the basic principles of fast breeders have been known for as long as efforts have been made to use nuclear energy in reactors. In 1951, a small experimental breeder, operated by the U. S. Atomic Energy Commission, generated the world's first electricity from nuclear energy.

Fusion Reactors

Fusion, the process by which the sun and other stars generate their energy, is a nuclear reaction that could become a virtually unlimited source of energy for mankind for thousands of years without the safety, environmental, and waste disposal problems of other nuclear reactions.

In contrast to fission (splitting) of the nuclei of heavy elements, fusion is the process of combining (fusing) the nuclei of light elements to produce large quantities of heat energy.

However, the fusion of these light nuclei will take place only at a temperature of many millions of degrees. To date, the reaction has been successfully demonstrated in the laboratory for very short periods of time, but not in the sustained fashion required for power plant operation.

Despite the difficulties of applying the fusion principle, its importance is so great that many substantial research efforts are under way, particularly in the U. S., the U.S.S.R., and Western Europe. There are two main approaches being followed to achieve controlled fusion power. One is through the use of magnetic fields to contain the high temperature fuel; the other is through the use of laser energy to heat fuel pellets to reaction temperatures.

The most important feature of the fusion reactions now being investigated is that the light elements involved—mainly isotopes of hydrogen—exist in the ocean in almost unlimited quantities that could supply large amounts of energy for millions of years.

Most estimates, while optimistic regarding eventual success of the fusion method, project its commercial realization at about the end of this century. Beginning about that period, however, it shows great promise of becoming the most desirable solution to the energy problem for many centuries to come.

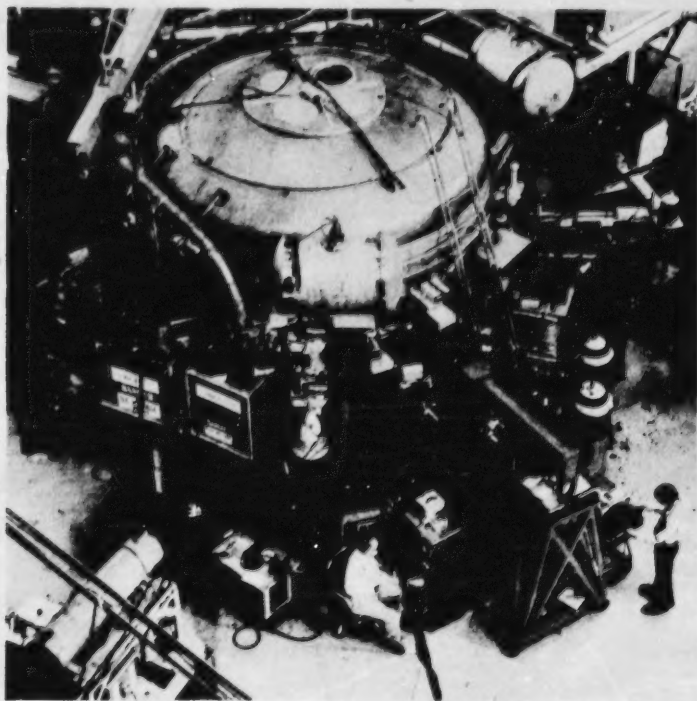


Figure 11 ERDA's ORMAK fusion research experiment in Oak Ridge, Tennessee.

SOLAR ENERGY

No source of energy is as clean, abundant, and inexhaustible as sunlight and some of its secondary effects, such as the winds and the differences in temperature between the tropical ocean surface and the waters in the depths. The idea of harnessing this energy is inherently attractive because it is a "gentle" technology that emits almost zero pollutants and exacts a far smaller penalty on our environment than some other energy-production activities.

In theory, an earth-based solar collector $\frac{1}{500}$ of the area of the United States (an area slightly smaller than Massachusetts) receives an amount of solar energy that, if converted at 20% efficiency, would provide for all of the Nation's present consumption of electricity.

In fact, however, there are technical, economic, and institutional barriers to the immediate and widespread use of solar energy, and overcoming them will take decades of work. The technical barriers to using solar energy are associated with two facts about the sun's rays: They are spread diffusely over the surface of the earth and they are intermittent; the sun shines only by day and is frequently obscured by clouds. To harness large amounts of solar energy, collectors must be spread over a large area, and the larger the facility, the higher the cost. With most techniques, only a portion of the collected solar energy is used immediately. The rest must be stored. The cost of storage is usually a significant fraction of the cost of operating the installation. Thus one of the major areas of research and development that must be pursued to improve the outlook for solar energy utilization has to do with finding ways to store large amounts of energy at low cost.

The economic barriers to utilization of solar energy result from the fact that high initial costs are required for solar energy facilities, even though the operating costs are low. Someone has to borrow money to build these facilities. This

is often a problem even for governments and large businesses. For individual homeowners, it is even more of a problem.

The institutional barriers of using solar energy result from out-moded thinking. People and institutions do not usually give serious consideration to lifetime energy costs when they construct a facility or a residence. Because of the historic low costs of fossil fuels, there has been no economic incentive to establish industries that manufacture, install, guarantee, and maintain solar energy equipment.

Six major approaches to using this energy source are being followed in the national solar energy program under the leadership of ERDA. Two approaches involve the direct utilization of the sun's light and heat. The others are techniques for converting solar energy into electricity. The six, listed in order of their potential for large-scale near-term benefits, are:

- Heating and cooling
- Wind energy conversion
- Bioconversion to fuels
- Solar thermal conversion
- Photovoltaic conversion
- Ocean thermal energy conversion

Solar energy for heating and cooling is the most immediately promising application because it is technically simple and because approximately one quarter of all United States energy consumption is for space heating, water heating, and air conditioning—at a cost of more than \$25 billion a year.

Wind is another area that promises relatively short-range use of solar energy if economic and institutional barriers can be overcome. If ways can be found to use wind-generated energy directly or to store it at low cost, this source can provide needed additional electrical generating capacity in areas of the country where there are relatively high winds.

Still another technique of using solar energy is to accentuate the natural processes of photosynthesis in plant

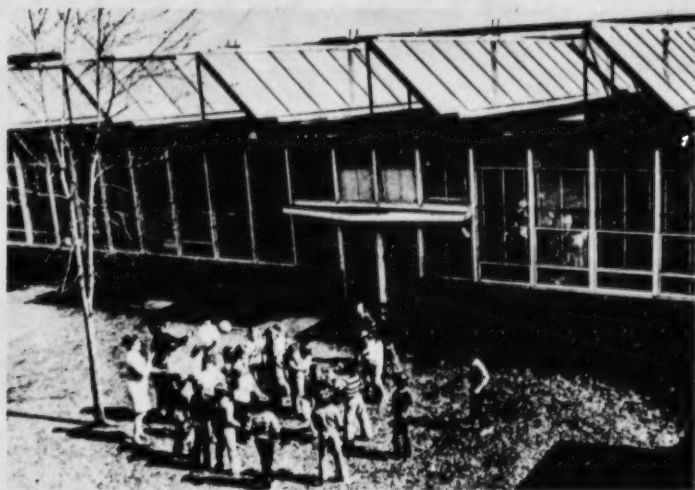


Figure 12 Pupils and teachers at Timonium Elementary School in Maryland play volleyball in front of the wing that is heated by a solar energy system. Glass panels on the roof trap the sun's warmth, which then heats piped water.

life. There are many ways to do this; again the problems are mainly economic and institutional.

The ERDA program of bioconversion to fuels is working to establish the commercial practicability of producing significant quantities of plant materials at feasible costs. The goal is to convert these materials and other organic products now considered wastes into clean fuels. The four major sources of materials being examined are urban solid wastes, agricultural residues, and terrestrial and marine crops. End products that may result include synthetic natural gas, alcohol fuels, solid fuels, heat, electricity, ammonia nitrogen fertilizer, and petrochemical substitutes.

Somewhat longer time scales are associated with developing techniques for generating electricity from solar energy. One such approach will employ high-temperature thermal

conversion. Experiments are under way to use various means to collect and concentrate the sun's rays on pipes coated with materials that would absorb the sunlight as completely as possible and reduce re-radiation of heat outward. But this application illustrates some of the economic barriers very graphically. A 1000-megawatt power plant of this design would require a collection area of about 10 square miles if located in the southwestern United States, where solar radiation is high. Estimates of the cost of such installations vary widely.

Another long-range potential contributor of electric power is the photovoltaic technique used in photographic light meters and solar cells in space. In certain substances the absorption of light creates an electrical voltage that can be used to generate an electric current in an external circuit without any additional power sources. The solar cell array on the Skylab space station orbited in 1973 cost about \$2 million per kilowatt to build, which is about 4000 times the cost of power generation capacity using coal-fired or nuclear plants on earth. It is estimated, however, that present mass production techniques might produce silicon solar cell arrays at a cost of \$10,000 per kilowatt and that this could be reduced to \$2500 by developing an inexpensive process for producing cadmium sulfide cells. The goal of the photovoltaic program is to drive costs down ultimately to about \$500 per kilowatt.

The longest range application of solar energy involves making use of differences of 40°F or more between the temperatures at the tropical ocean surface and a half mile below. These differences can be used to drive turbines that operate through the boiling and condensation of liquids such as propane or ammonia. Research has progressed through the solution of some design problems, and engineering organizations have evaluated the feasibility of various concepts. Planning is based on the construction of demonstration plants by the mid-1980s and commercial implementation by the end of that decade.

GEOTHERMAL ENERGY

Geothermal energy, the heat inside the earth, is a vast, potentially valuable source of energy. According to current scientific theories, this heat is the result of the slow decay of radioactive materials and friction from crust movements within the earth's interior and would be available indefinitely. Actually, its commercial use for generating electricity dates back to 1904 in Italy. Today, electric power is being produced geothermally in New Zealand, Japan, the United States, Iceland, Italy, Turkey, Mexico, and the Soviet Union. Basically, there are three ways in which this type of heat energy can be used—through steam, hot water, and hot dry rock.

The only geothermal resource in commercial use in the U. S. is in California at The Geysers steam field, north of San Francisco, where an electric generating plant of about 500 megawatts—enough for a city with a population of approximately 250,000–500,000—is being operated. Steam of relatively low pressure and temperature is collected from wells, filtered, and passed through turbines, which operate electrical generators.

Figure 13 Plants No. 5 and 6 at The Geysers, a natural steam field in California.



Although the relatively lower pressures and temperatures of this steam result in reduced efficiency, as compared with a typical steam power plant, The Geysers type of installation costs less to build and operate than comparable fossil or nuclear plants.

Plans are under way to add more than 100 megawatts of capacity to The Geysers field every year for several years, so that the complex will eventually produce as much power as that used now by San Francisco. The total potential geothermal resources available at The Geysers field are estimated to be about 2000 megawatts.

Although wells in the Geysers region and in the Lardarello region of Italy produce steam without hot water, it is more common for geothermal wells to yield a mixture of steam and hot water, which is less convenient to use, since the steam must be separated before it can be used to generate electricity.

There are many places in the U. S. where hot water wells without steam are located, but none of these is used to produce power commercially. It has been proposed that one method of harnessing this energy would be an arrangement whereby the heat from the lower temperature water sources could be transferred to a secondary fluid of lower boiling point, such as isobutane, which would then be passed through a power turbine. Such an installation using freon is already in operation in the Soviet Union, and a small prototype unit using isobutane will be built on the west coast of the U. S.

By far the largest geothermal energy resource is believed to be dry hot rock at relatively shallow depths. One proposed method of using this dry heat is to crack the rock with water pressure and then to circulate water from the surface through the cracks to extract heat from the rock. This method of tapping hot dry geothermal deposits is being investigated at ERDA's Los Alamos Scientific Laboratory in New Mexico.

It is as yet uncertain whether use of dry geothermal resources will be feasible and economically competitive with other sources. Since, however, they probably represent the largest geothermal energy reservoir, it is worthwhile to conduct further work in this field.

It looks now as though the most probable course of development for geothermal energy in the near future will be the construction of power plants using hot waters, brines, or steam separated from hot water or brine deposits. Geothermal heat may also be used directly for various local household heating and industrial process applications, rather than converting it to electricity. The environmental effects of harnessing geothermal energy are largely confined to the immediate vicinity of the plants, but these effects are significant and must be carefully analyzed and controlled.

Geothermal power is not expected to replace either fossil or nuclear fuels as the major source of electricity generation at least in the foreseeable future. However, if a modest research and development program were undertaken, it has been estimated that by 1985 approximately 7,500–15,000 megawatts of geothermal power could be made available in the U. S. This would be about 2% of the total electrical capacity expected in the U. S. at this time.

ENERGY FROM THE WINDS AND THE TIDES

Space does not permit a detailed discussion of all available energy resources, but brief mention is made below of two that are not now used extensively but which historically have been the subject of attention from time to time. The bibliography provides further references.

One of the oldest forms of energy is the wind, which is indirectly due to solar energy absorbed by the earth and the atmosphere surrounding it. Since the beginning of recorded history, wind has been used to move ships on the sea and to operate windmills, mainly for pumping water.

In more recent times windmills have been gradually replaced by other energy sources, such as electricity and fossil-powered engines, because they became available at reasonable cost and were more dependable. Nevertheless, the possibility of using wind on a relatively large scale has been periodically examined in various countries. One major experiment was undertaken in the U. S. in 1941 in Vermont, but serious structural problems were encountered. Another large installation, financed by government funds, is planned in the near future.

The total amount of wind energy theoretically available is tremendous and inexhaustible. But large capital investments are needed to capture even a small portion of this energy, and, as every sailor knows, the wind is often not there when it is needed most.

An important factor in using the wind is the development of a convenient and efficient method of storing the wind's energy for future use as needed. An improved electrical storage battery, as discussed in the chapter on energy storage beginning on page 46, would be of great advantage.

Various proposals have been made over the years to harness the energy in the tides, particularly in those spots in the world that have a substantial tidal rise and fall. Considering the relatively few locations where such tides exist, the large capital investment involved, and the lack of a satisfactory storage means, there is little hope at this time that tidal energy will be important in the foreseeable future. To date, only one such installation has been operated in the world; it is on the Rance estuary in Brittany, France.

Energy Uses

Figure 14 shows how the total energy generated in the U. S., from the various sources shown in Figure 5, is divided roughly equally in 1973 into four main uses, or applications, as follows: industry, 28%; transportation, 25%; residential and commercial, 21%; and electricity generation, 26%.

Figure 15 is a set of four charts showing further the energy sources or forms that are used for each of the four basic applications.

Figure 16 indicates the future trends that are expected in these four broad areas of demand from 1970 through the year 2000. The total energy use in the U. S. is expected to increase during this 30-year period by 200%. In other words, it will multiply by a factor of 3.

Of particular significance also is the estimate shown for the energy devoted to electricity generation, which is projected to rise by 390% (by a factor of almost 5) during

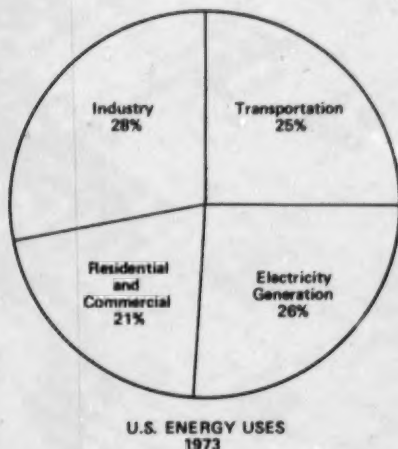


Figure 14

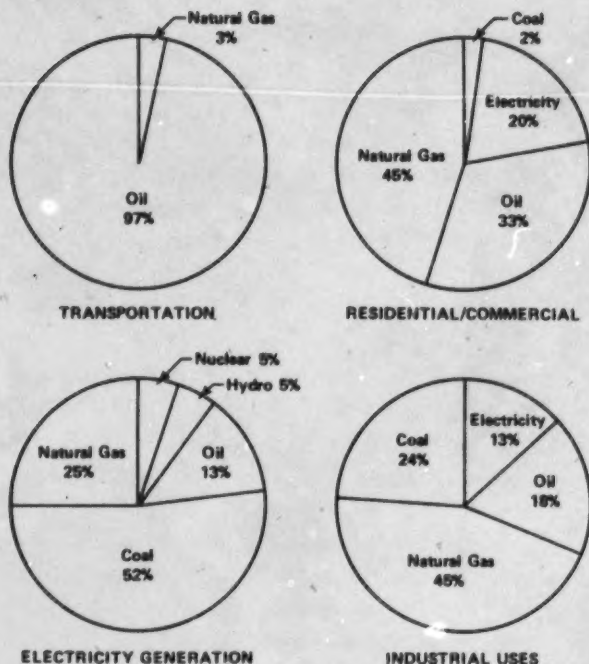


Figure 15

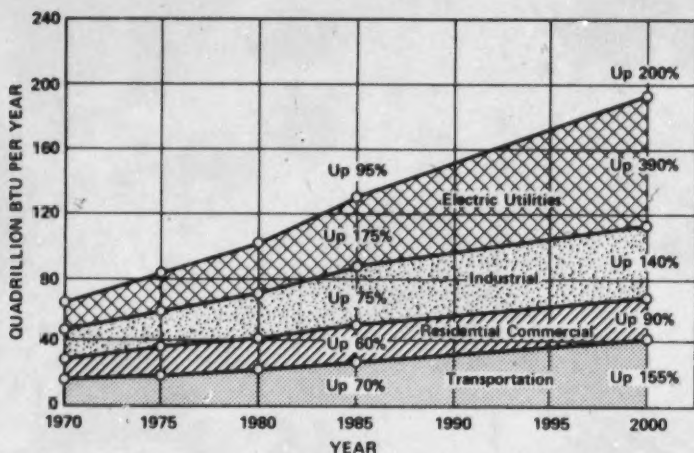


Figure 16 Averaged projected demand for direct use of primary energy.

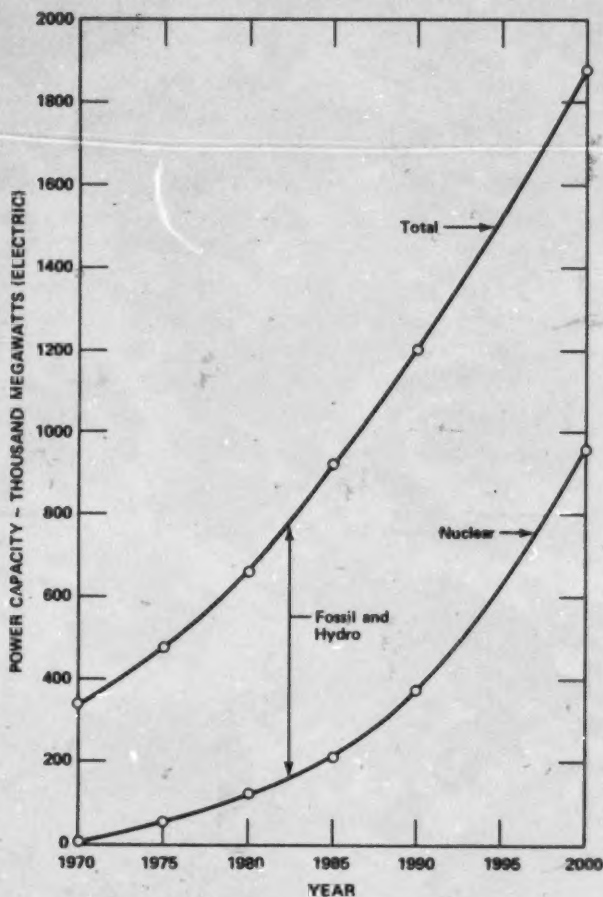


Figure 17 Projected electric power generation capacity through the year 2000.

this time. The electric power trend is shown more vividly in Figure 17.

Figure 18 shows how the U. S. trend in energy demand compares with other parts of the world for the last three decades of the 20th century.

It is significant that, while the U. S. was responsible in 1970 for about one-third of the total energy consumed in the world, in the year 2000 its share is expected to be only 22%, even though in total amount it will have increased by a factor of 3!

The reason is that many other parts of the world will increase their energy use by an even greater factor than the U. S. (See Figure 18.)

The total anticipated world energy use at the end of the century is forecast as being over four times what it was in 1970.

These data on present and expected future demands for energy, both in the U. S. and abroad, emphasize vividly the need for rapid advances in energy technology.

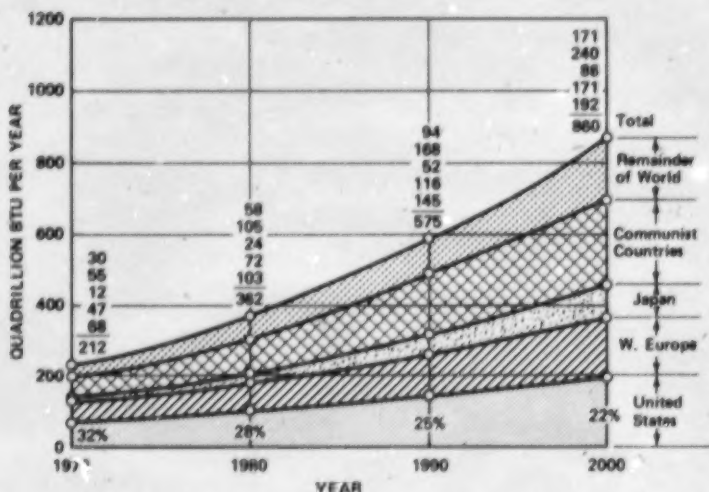


Figure 18 Projected world energy demand through the year 2000.

Energy Conversion

All experience indicates that, although energy may be converted from one form to another, it is never really lost, in the sense of disappearing. Generally, the difference between the total energy that is put into a particular machine or power unit and what comes out as usable work is given off in the form of heat.

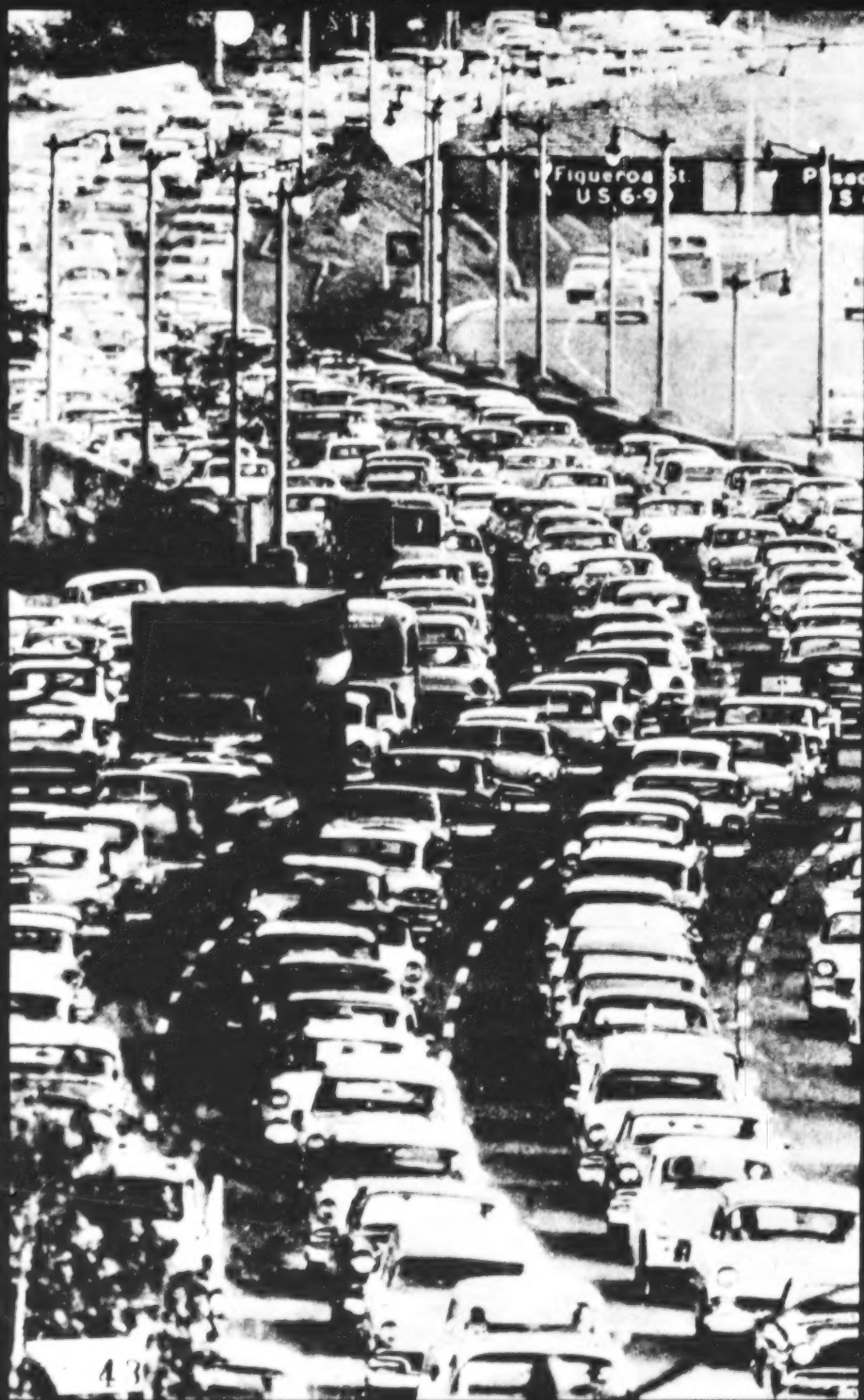
In an automobile, less than 25% of the energy contained in the gasoline is ordinarily converted to mechanical, or kinetic, energy. The remainder is dissipated as heat in the radiator. Steam-electric power plants dissipate as heat about two-thirds of their total input energy, on the average, which has given rise to the environmental problem known as "thermal effects".

Many kinds of energy conversion occur in daily life. For example, there are numerous ways in which electricity may be converted in our homes and offices into heat, light, air conditioning, or mechanical motion. Heat can also be transformed through several steps into mechanical motion and then electricity, as it is in a power plant. The reverse is true when mechanical motion is translated into heat, which is what happens when a hammer heats up the nail it pounds.

The potential energy of the water in a dam can be converted to kinetic energy and then electricity. An electric battery can convert chemical energy into electrical energy directly. Radiation, such as sunlight, can be converted directly to heat, or to electricity through the use of solar cells. (See also the chapter on energy resources on page 14.)

There are very precise relationships between the corresponding amounts involved when various forms of energy are converted back and forth. Thus it is possible to calculate in advance just what can be expected in any given transfer.

The efficiency of various kinds of energy conversion varies widely as shown in Figure 20. It is helpful in studying energy technology to keep a few of these in mind. For



example, the transfer of mechanical motion into electricity by means of a generator is close to 100% efficient; the reverse, the conversion of electricity into mechanical motion in an electric motor is about 90% efficient.

On the other hand, the conversion of heat to mechanical motion is less efficient. For example, in steam turbines it is about 45%; in automobile engines it is less than 25%. Such conversions involve large amounts of waste heat, which is the identifying characteristic of inefficient processes.

The basic principles, or laws, of nature, which govern interactions between mechanical energy and heat, are part of the science of thermodynamics. One of these fundamental facts is that the efficiency of conversion from heat energy to motion (and in turn, to electricity) is limited by the difference between the original temperature of the heat used in the process and the final temperature of the heat discharged.

For this reason, currently operating pressurized-water nuclear power plants operate at a lower efficiency (about 32%) than do modern fossil-fueled plants, which have efficiencies of 38 to 40%. This is because these nuclear plants use steam at a lower temperature than that used in the fossil plants. Consequently, such nuclear plants give off more waste heat than the most efficient fossil plant of the same electrical capacity.

Since the waste heat from all electric power plants is inevitable, and is a result of the laws of nature, it is one of the objectives of energy technology to develop methods of usefully employing such heat, for example, in heating houses and to accelerate the growth of aquatic life. Progress is being made along these lines, but there are inherent limitations due to the small temperature difference between the heat



Figure 19 Less than 25% of the energy contained in gasoline in a car is ordinarily converted to mechanical, or kinetic, energy. The rest is emitted as heat.

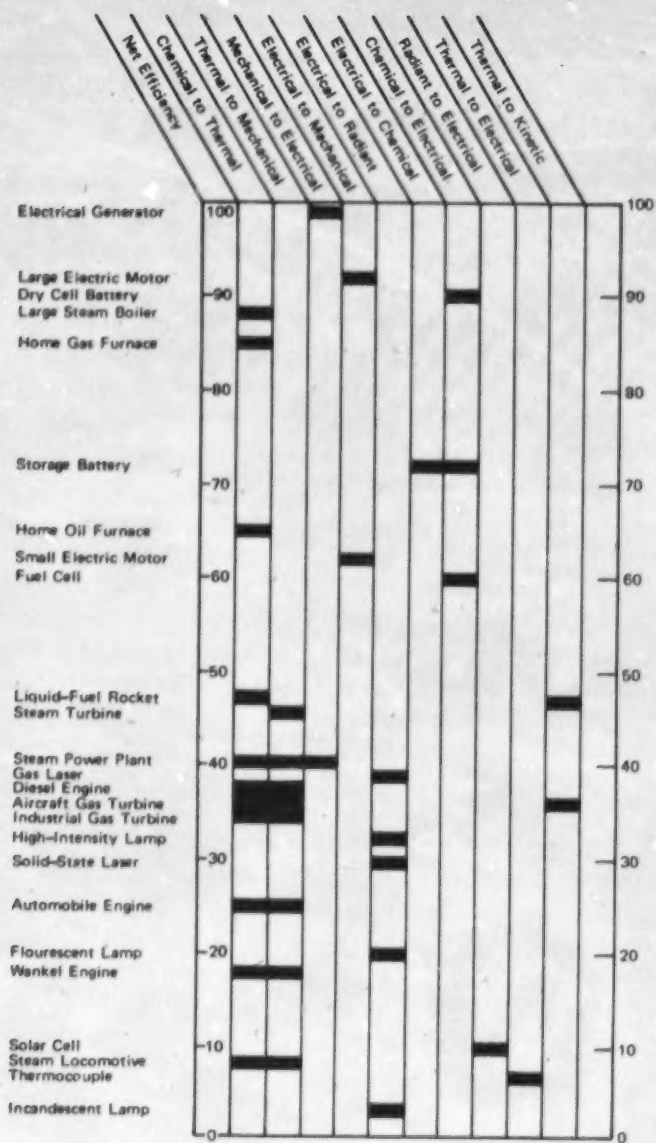


Figure 20 Efficiency of energy converters runs less than 5% for the common incandescent lamp to 99% for large electric generators. The efficiencies shown are the best approximate values attainable with present technology.

discharged and the environment. If the plant design is changed to discharge waste heat at a higher temperature, the overall efficiency is reduced accordingly.

The conversion of electricity either to heat or mechanical motion is relatively efficient. It is interesting to compare the amount of heat generated by a specific quantity of electrical energy with the mechanical work produced by the same amount. For example, if a kitchen toaster, rated at 1000 watts (equivalent to $1\frac{1}{3}$ horsepower), is left on for 1 hour it will use up 1 kilowatt-hour of electrical energy. This quantity of electricity converted to mechanical work (2,640,000 foot-pounds) would be sufficient—neglecting friction, of course—to lift an average man from sea level to the top of Mt. Rainier (14,410 feet) or raise 25 men from the bottom to the top of the Washington Monument (555 feet).

In either case, the cost would be between 2 and 3 cents, which is the average price paid today in the U. S. for 1 kilowatt-hour of electricity.

FUEL CELLS

Electricity can be generated when hydrogen and oxygen are chemically combined to produce water. This is the simplest type of "fuel cell", which is a kind of battery in which one or both of the electrodes (or terminal components) is replenishable. The hydrogen-oxygen fuel cell is a relatively simple and efficient method (above 80%) of producing electricity, but it is expensive.

The fuel cell offers many advantages for certain special applications, for example, in space vehicles. But it is not yet economical as a method of generating large amounts of power.

The hydrogen required for fuel cells is widely available in such compounds as ammonia, methane, and even gasoline, but it is expensive to extract the hydrogen, and there are complex technical problems in using these fuels directly.

In later discussions of the hydrogen economy, the use of hydrogen to generate electricity through fuel cells is included as one of the end-use applications for hydrogen that is distributed through a large network.

MAGNETOHYDRODYNAMICS (MHD)

For almost a century, one of the objectives of energy conversion research has been the generation of electricity by causing a conducting gas, or plasma, to flow through a magnetic field. The principle of magnetohydrodynamics is similar to that of an ordinary electrical generator except that the moving plasma replaces the conducting wire.

In operation, the conducting gas may be a fossil fuel burning at high temperatures, which assumes electrical properties as it moves through a channel, whose sides generate a voltage.

The MHD principle has been extensively investigated recently both in the U. S. and the Soviet Union, and large experimental generators have been built and tested. One application is to use MHD as an initial stage, or "topping unit", for a conventional steam plant with a resulting increase in overall efficiency from 35 to 40 to 50% or greater.

While MHD systems offer the potential advantage of higher efficiencies, it has not yet been established that they are practical for commercial use and competitive from an economic standpoint. The high temperatures require developing exceptional materials.

THE HYDROGEN ECONOMY

The hydrogen economy, a highly sophisticated and novel systems approach to the whole problem of energy conversion, distribution, and storage, is based on the use of hydrogen (which has been separated from water electrically at central production centers) as an energy source to be piped

to local storage or usage areas. The hydrogen would be burned to produce heat, used as a transportation fuel, in industrial processes, or in fuel cells to generate electricity. Such a system, while possessing some important environmental advantages, would involve the replacement of a large fraction of our present extensive electrical distribution network with hydrogen pipelines; this would be a capital investment of great magnitude. There is also a basic economic problem because the cost of producing the hydrogen is greater than that of generating electricity by current methods.

Energy Storage

Energy storage is used in this booklet to refer collectively to the various methods and techniques that have been investigated and developed to store energy in such a way that it can be usefully and conveniently employed where and when it is required. Some of the more significant concepts are outlined in this chapter. Hydrogen production, storage, and reversion to electricity is one method of energy storage, which was discussed in the previous chapter.

PUMPED STORAGE

Nature does the work of storing water behind man-made dams, so that the water can be used upon demand to generate electricity (as in hydroelectric plants). Recently a variation of this process, called "pumped storage", has been widely considered by the electric utility industry and is being put into practice in various locations in the U. S.

The basic idea is to use a portion of the electricity generated by a steam-electric plant (either fossil or nuclear) during periods of slack demand to pump quantities of water up to a higher level reservoir. Subsequently, during periods of peak demand, this water is allowed to generate electricity as it flows to a lower level, for example, in a hydroelectric installation, to augment the capacity of the steam plant.

Thus a power plant with pumped storage capability can meet specified peak loads and still be smaller than a plant capable of meeting such loads without storage facilities.

Where the terrain permits, the use of a pumped storage concept results in an overall cost savings in power plant construction as well as a steadier—and hence more efficient—operating schedule. Its expanded use by the power utility industry is limited because of the small number of sites available for building additional facilities in an

environmentally acceptable manner. Underground pumped hydroelectric power is being investigated and may be a method of extending this technology.

ELECTRIC BATTERIES

An important method of storing energy is an electric battery, which stores electric energy chemically.

Two general types of batteries are: primary batteries, such as flashlight batteries, which are designed to be used until exhausted; and secondary batteries, such as automobile storage batteries, which are intended to be recharged and used repeatedly. This discussion will concentrate on the latter type.

The availability of electricity from batteries was first studied early in the 19th century. Early practical applications of electricity, such as the telegraph and telephone, were powered entirely by batteries. For example, the first U. S. telephone exchange, established in New Haven, Connecticut, in 1878, was energized entirely from batteries. Yet, it must be pointed out that not many important breakthroughs in battery technology occurred in the period 1910-1950. But in the early 1960s a renewed interest in batteries occurred because of the need for energy storage systems for the space program.

Currently, the most promising line of attack appears to be a high-temperature battery system, such as one using lithium and sulfur. This design, still in the development stage, has some important properties, such as high energy and power density, but does not yet meet necessary long life and cost criteria. ERDA's Argonne National Laboratory near Chicago, Illinois, has undertaken an extensive program in this field.

Several vital applications where improved storage batteries would have a substantial impact on energy technology are described briefly below.

One important application would be the use of large secondary batteries to store electrical energy generated by power plants during daily off-peak periods for delivery during subsequent peak periods. This is a function similar to that provided by the pumped storage concept outlined above. The advantages, which are identical, are to reduce the investment otherwise needed to cope with wide variations in the demands made on the utility generating and transmission facilities, and to reduce use of oil.

Other advantages are: the possible urban siting of such batteries, without environmental effects, near heavy load centers; reduction of the costs of the transmission system, which would not have to be built to accept peak loads; modular size design possibilities; short construction lead time; and greater system design flexibility.

At least three other important applications for improved storage batteries, quite apart from their obvious usefulness in all kinds of portable devices, are mentioned below because of their significance.

The first of these is the opportunity to take much more advantage of solar energy through the use of a high-efficiency battery that would be charged while the sun is shining and provide electricity when it is not.

The second such application would be the possible extensive use of batteries to provide power for electric vehicles, thus significantly reducing the demand for petroleum and enhancing urban environmental air quality. A large fraction of such vehicles could be charged during the off-peak night hours, and this would minimize the need for additional generating facilities.

The third possible important use would be to store electricity generated by windmills. A much improved storage battery would have a definite influence in bringing back the windmill, a device that uses a form of free energy and is particularly important in remote locations. (See also the chapter on energy resources on page 14.)

COMPRESSED AIR STORAGE

Compressed-air storage is a technique intended to increase the fuel efficiency of gas turbines that now account for the peaking power of electric utilities to the extent of about 6% of the total U. S. electrical generation capacity.

A major part of the power produced by a gas turbine is used to compress the air that is injected into the combustion chamber. If compressed air is available from an external source, the electrical output of a gas turbine can be increased by a factor of 2 to 3 with the same quantity of fossil fuel.

In the air storage concept, the air would be compressed in off-peak periods, stored in underground caverns, and used during peak demand periods to increase the output of gas turbines.

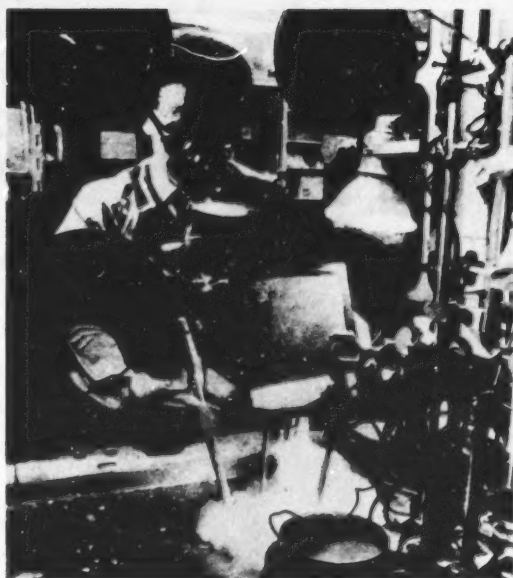
Further investigation into costs associated with the concept is needed in order to determine the overall economics of compressed-air storage plants, to locate sites, and to develop the system. Disadvantages are that the location of suitable sites may be far from the load center and the need for fossil fuels.

ROTATING FLYWHEELS

Storing kinetic energy in a rotating flywheel is probably familiar to almost everyone in the form of a small toy car that runs a few feet on such energy after the flywheel has been wound by hand.

There is considerable evidence to indicate that the flywheel is actually man's oldest known energy storage device; for example, part of a 5500-year-old flywheel has been unearthed!

More recently, large flywheels have been used to store energy for use in providing uninterrupted power in such equipment as computer installations, helicopter hoists, buses, and large power shovels. A flywheel on a power shovel, for



example, can level out the power demands and keep them in the range of 40 to 50% of the peak power load. The same principle applies to other applications, for example, in the New York subway.

The first commercial use of flywheel energy storage in a vehicle was in the so-called "gyrobus" that was developed and used in Switzerland. The 35-passenger gyrobus drew electric power from overhead poles spaced about $\frac{1}{2}$ mile apart. The flywheel, which provided energy to drive a generator that in turn powered the bus, was speeded up at each pole.

Since 1900, it is estimated that there has been a tenfold improvement in flywheel energy storage technology. Flywheel energy storage technology is currently undergoing a revolution. New high-strength materials and construction techniques would reduce the danger of flywheels breaking at the high speeds required.

Figure 21 Argonne National Laboratory's concept of a high-energy, rechargeable lithium-sulfur battery is following two approaches: a clean power source for automobiles, and an energy storage center for electricity during off-peak load periods. Left, below, are the components of a lithium-sulfur storage cell. The lithium electrode is being installed in the case; the sulfur electrode (left) is on top of a thin ceramic cloth that separates the two electrodes. A current feed-through (center) connects to the sulfur electrode to conduct electric current through the case when sealed with the cap (right). Before sealing, the case is filled with a molten-salt electrolyte. Left, above, a laboratory-scale lithium-sulfur cell produces sparks and smoke—just like touching the negative and positive wires of a conventional battery—as it undergoes testing. The experimental cells are handled in a glove box containing an inert gas to prevent reaction between the components and oxygen. A furnace in the floor of the box is used to heat the cells to operating temperature.

HEAT STORAGE

The problem of convenient storage of heat has been paramount ever since experiments were undertaken to use solar energy for house heating. One approach is to identify a substance that has the appropriate physical characteristics so that it changes from a liquid to a solid (and vice versa) and thus gives up (or absorbs) its substantial "heat of fusion" at a temperature practical for house heating. To date, no really satisfactory substance has yet been found that is also acceptable from a cost and volume viewpoint. A solution to this problem would have great significance.

SUPERCONDUCTING COILS

As covered in more detail in the next chapter, the use of extremely low temperatures to bring about an almost perfect electrical conductivity in certain materials might have an application for energy storage. The concept would involve setting up large electric currents in huge conducting coils at very low (cryogenic) temperatures. The current would continue to flow for a long period of time with a relatively small percentage loss and would be available as an energy source upon demand. This technique is being investigated at several laboratories including the University of Wisconsin and ERDA's Los Alamos Scientific Laboratory in New Mexico.

Energy Transmission

Transmission of energy covers many varied activities, including the transportation of fossil fuels, such as coal, oil, and gas, by all the standard methods such as train, truck, tanker, and pipeline. It includes also the transmission of electricity on which we will concentrate in this chapter.

Despite the many advantages of electricity, its transmission by today's techniques is unfortunately more expensive than most methods of energy distribution. For example, if proper weight is given to the average efficiency of conversion of fossil fuels to electricity, then electrical transmission is a little more expensive than shipping coal by ordinary trains. It is still more expensive than shipping fossil fuels by other methods, such as unit trains and pipelines.

If it is necessary to transmit electricity underground, because of esthetic reasons and land availability, then the cost increases by a large factor. Thus, if large power stations are going to be located far from population centers, it is very important to develop less expensive and more efficient methods for transmitting electricity, both above and below ground. In this connection, it is of interest to recall an historic anecdote that is concerned with the transmission characteristics of alternating current versus those of direct current.

THE WESTINGHOUSE-EDISON ARGUMENT

In the early part of this century, a bitter argument raged for years between the two world-famous inventors, George Westinghouse and Thomas Edison, on the subject of electricity transmission.

Edison contended that alternating current (AC) was inherently more dangerous than direct current (DC), and that DC should therefore be used in households, factories, and streets.

But since no practical method existed for changing DC voltage, the electricity had to be generated and transmitted at its final relatively low terminal voltage. This in turn required large currents, bulky and expensive cables, and high losses. Thus, Edison was never able to extend electrical service more than about a mile from any DC generating plant.

Westinghouse argued, on the other hand, that AC could indeed be used safely with proper precautions. And the overwhelming advantage of AC is that it can be readily transmitted over long distances through the use of transformers to convert the electrical energy to very high voltages and low currents. Near the point of final use, the transmitted high AC voltage is again changed through "step-down" transformers to the lower voltages that can be used safely.

Thus, Westinghouse won the argument, and the result has been that through the use of AC "high lines" or "high tension lines", electricity has been transmitted to many remote areas of our nation, including more than 98% of all farms.

But recent technical developments offer a distinct possibility that there may yet be an ironic twist to the Westinghouse-Edison controversy. Advances in apparatus for DC transmission systems have made this form of power transmission more attractive. Utilities are now considering DC transmission (both overhead and underground) for a variety of special situations.

UNDERGROUND TRANSMISSION

Three new technologies are being studied for underground power transmission from power plants to major consumption centers in order to avoid some of the major disadvantages of overhead power lines.

These new concepts are: cables insulated with compressed gas; cables cooled to the temperature of liquid nitrogen (cryoresistive lines); and those cooled to such an

extremely low temperature (cryogenic superconducting lines) that they become "superconducting", or virtually without electrical resistance.

As yet no cryoresistive or superconducting cable has been installed commercially, although some short compressed gas lines are already being used. There is a great deal of research work being done on these methods by government agencies, industry, and the utility-financed Electric Power Research Institute (EPRI). It is still not clear which of the three is likely to emerge as the most successful. Perhaps all three will find application.

Present-day underground cables are limited by the inability of the earth to absorb heat produced in the cable. Such heating can be effectively reduced and controlled by using more recent cable technology.

CRYOGENIC CABLES

It has been known for many years that certain materials lose almost all resistance to the flow of electricity when cooled to near absolute zero (cryogenic temperatures), which is about 450° below zero on our standard Fahrenheit scale.

It is only recently, however, that this characteristic, called superconductivity, has been successfully used for engineering applications, such as electric transmission cables.

Such superconducting cables potentially could transmit, through a single cable circuit, quantities of electric power that are virtually unlimited when compared to the power handling capabilities of conventional cables.

While these cables are more expensive and complex than conventional cables and are not suited for all transmission applications, their extremely high capacities will result in important cost savings per unit of power transmitted, when used for major circuits feeding power into large metropolitan areas. They also possess important safety and environmental advantages.

ERDA has an active program on cryogenic power transmission and is drawing on valuable expertise developed in its national laboratories under other programs, such as high-energy physics and controlled fusion.

The research and development effort supported by ERDA in this important field will strengthen U. S. industrial capability to provide sophisticated systems of this type to U. S. utilities and to the world market. Many other countries, such as Japan, Britain, the Soviet Union, and West Germany, have extensive programs supported by both government and industry.

By the late 1980s, full-scale commercial superconducting cable systems will probably be carrying many times the power now carried by existing cables. In fact, evidence to date indicates that superconducting cables may be the only practical way to transport large blocks of electric power into the cores of major cities. The underlying basic scientific principles are well established, but costs must be reduced and engineering problems solved before these cables can be used.

Energy Technology and the Environment

Since the beginning of time, man's activities have had an impact, directly or indirectly, on his environment.

The undesirable environmental effects, caused by human activities, have taken many forms. Chief among these have been: human and animal wastes; agricultural and mining activities that destroy the usefulness of land; and in more recent times a host of industrial, household, and transportation wastes related to the increasingly sophisticated character of civilized activities.

Public reaction in the U. S. to the constantly worsening pollution during the 1960s culminated in the enactment of the National Environmental Policy Act of 1969, which is a strong statement of public policy on the environment and the need for its preservation at an acceptable quality level in an affluent and complex society. The U. S. Environmental Protection Agency was also formed to establish and enforce environmental standards.

There is a relationship between energy technology and the environment in many different areas. For example, in the past the burning of coal and oil for industrial and household purposes, as well as for electricity generation, has given rise to serious pollution. More recently, the existence of over 100,000,000 vehicles on the road in the U. S. has added a whole new element of air as well as solid waste pollution.

However, not all environmental pollution is connected with energy sources and their use. On the positive side, large amounts of energy have proved to be increasingly necessary to combat or reduce pollution in such areas as sewage disposal, industrial air and water purification, and solid waste handling. These applications all involve large expenditures, however, and their use must always be a compromise

between available funds and desirable environmental objectives.

One of the principal broad functions of energy technology is to find techniques for continuing to supply energy wherever it is needed, but with pollution levels maintained to meet the standards of both the Federal Government and local governments. Much of the material in the preceding sections of this booklet was concerned with methods and concepts for supplying energy in an acceptably clean manner.

Some of the more important technologies that will have a definite influence on reducing environmental pollution are: increased use of nuclear power plants, which create less pollution than most fossil plants; gasification and liquefaction of coal, with the undesirable impurities removed in the process; electric vehicles based on improved storage batteries; and accelerated development of solar and geothermal energy.

In the last analysis, it is U. S. citizens who will decide through their elected representatives where the balance will be struck between the quality of life that accompanies large-scale energy utilization and the quality of the environment which is a part of that life. The availability of adequate energy technology and the support provided for its continued development will be an important factor in achieving such a balance.

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